THE FUTURE OF AGRICULTUTRE: AGRICULTURAL TRANSFORMATION CLUSTERED GREENFACTORIES

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Abstract

A forecast view of agricultural production is outlined inside a new type of building with photosynthetic walls and in vitro culture inside it. Recent advances in genetic engineering, nanoelectronics, biosensors and bionic building will make this futuristic type of greenhouse possible.

Introduction

Looking ahead to year 2200, activities associated with agricultural engineers have influenced world characteristics all through previous centuries, in areas such as:

- population increase;
- water availability;
- food production;
- land usage;
- biodiversity; and
- energy consumption.

Population

Despite humanity's success in feeding a growing world population, the natural resources upon which life depends, i.e. fresh water, cropland, fisheries and forests, are weakening. In the new millennium the population growth is slowing at a much faster rate than was previously predicted. However, significant growth continues, meaning that more people will be sharing such finite resources as fresh water and cropland.

Having reached nearly 6.1 billion in 2000, the human population continues to grow. Population projections for the year 2025 range from 7.2 billion to 8 billion and for 2050 range from 7.9 billion to 10.9 billion, suggesting the extent to which we can influence our future. More people and higher incomes worldwide are multiplying humanity's impact on the environment and on natural resources. (Hardner & Rice, 2002; UNFPA, 2002)

Water

Water may be the resource that defines the limits of development. The supply of fresh water is essentially fixed, and the balance between humanity's demand and the available quantity is already precarious. While global population has tripled over the past 70 years, water use has grown six-fold. Worldwide, 54% of the annual available fresh water is being used, two thirds of it for agriculture. By 2025, this figure could be as high as 70% because

BIO NOTE

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of population growth alone, or 90%, if per capita consumption everywhere reaches the level of more developed countries.

Currently, 434 million people face either water stress or scarcity. Depending on future population growth rates, between 2.6 billion and 3.1 billion people may be living in either water-scarce or water-stressed conditions by 2025 (UNFPA, 2002). For 2025, water usage will be 800 km^3 higher, and other related problems will worsen, such as soil salinity and underground water (Hardner & Rice, 2002).

Food

To accommodate close to 8 billion people, expected on earth by 2025 and improve their diets, the world will have to double food production. Since available cropland is shrinking, most production will have to come from higher yields, rather than new cultivation. However, traditional high yielding crops require increasing levels of input. Taking into account the crop surface to extract a certain quantity of protein and also that required to feed an animal to produce the same quantity of animal protein, the conclusion looks clear. In a decreasing worldwide crop surface, the source of proteins must come from photosynthetic organisms.

Land

Agriculture uses more than 50% of the inhabitable areas of the planet at present. Urbanization also affects food production by removing agricultural land from cultivation, as cities expand. On the other hand, agricultural activity is one of the bigger threats to the environment, having contributed to:

- deforestation;
- pollution of water;
- salination of soils; and
- extinction of species (Jason Clay & WWF, 2003; Postel, 2001).

The introduction of agrarian activities and cattle in wild areas does not always end in an economic improvement for the inhabitants of the zone (Hardner & Rice, 2002). A strong demand for land actually pushes traditional crop fields away from the landscape.

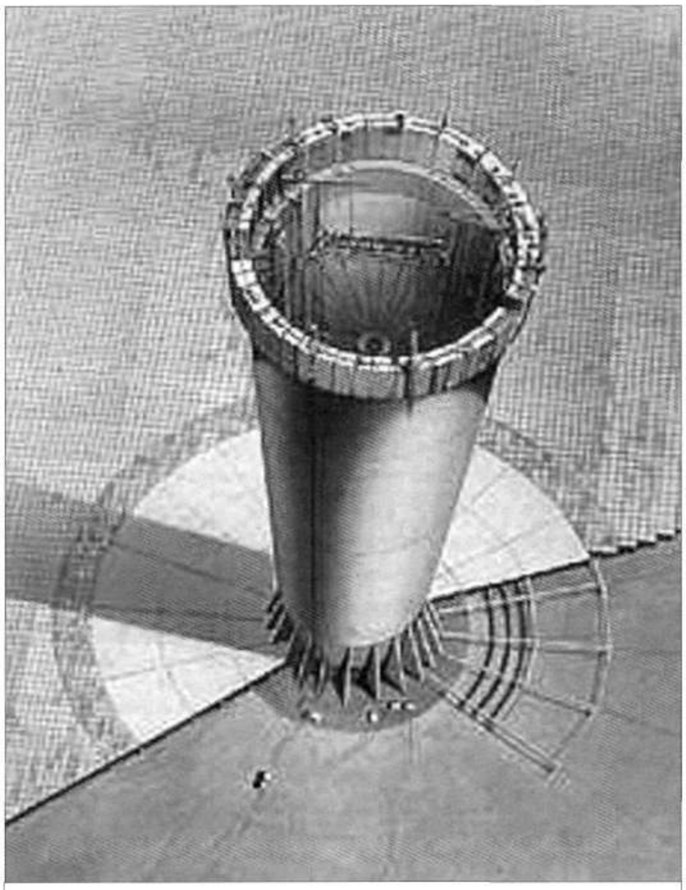

Fig. 1 3D tower view illustrating the magnitude of the enterprise

Biodiversity and ecological equilibrium with urban areas

In the last few decades as population growth has peaked, deforestation rates have reached the highest levels in history. Deforestation of these areas cause irreversible loss of species and also contributes to the build-up of carbon dioxide in the atmosphere.

Wild landscape should be preserved, despite the evolution of big urban areas. The solutions to the urban problems of the future should face the new reality of mega cities.

Under the logic of energetic rationality, accepting that the conquest alternative of the vertical space facing the 'extension without limit' or the conurbation, the present model of the skyscraper is considered inappropriate, as much by its dehumanisation as by its technological limit. The inevitable technological progress should find its equilibrium with the 'bio-ecological' recuperation of natural medium.

Bionic science is shown as an alternative, for the philosophical reflection and the scientific development of humanity, in urban models. Bionic and bio-ecology are two innovative concepts of urban philosophy, and agricultural engineers have the potential to bridge nature and architecture.

Energy

The total consumption of the fossil fuels, oil and coal, would involve a radical change in the composition of the atmosphere, returning it to the carboniferous period conditions. Renewable sources of energy, especially the sun in its different exploitation forms, are the key for future production. Here, again, agriculture has much to say, not only in its role as energy consumer, but also as producer.

Objectives, materials and methods: available technologies

A solution should be planned separating food production from the land, with the following objectives:

- obtaining more land for housing
- maintaining ecosystems as preserved as possible, for recreation and biodiversity purposes
- creating a self-contained, high yielding production system which is autonomous in terms of energy and mass
- producing a diversified agricultural output (food, energy, materials and recycling)

The tools that agricultural engineers have to carry out this goal are:

- advances on renewable energies;
- artificial photosynthesis, biotechnology;
- 'in vitro' culture;
- genetics advances;
- bioelectronics;
- nanomechatronics;
- nanocomputing;
- new constructive materials; and
- bionic architecture.

Results and Conclusion: production inside ATCGs

Food production should be planned in high performance closed environments, built in volume (not surface), self supported in terms of energy and inputs (see Fig. 1). Production will be carried out inside a new building: *Agricultural Transformation Clustered Greenfactories (ATCG).*

Energy collection

There will be several ways of obtaining energy in an ATCG but mainly it will be obtained from energy from the sun. The most promising method is the artificial mimicking of photosynthesis and related solar

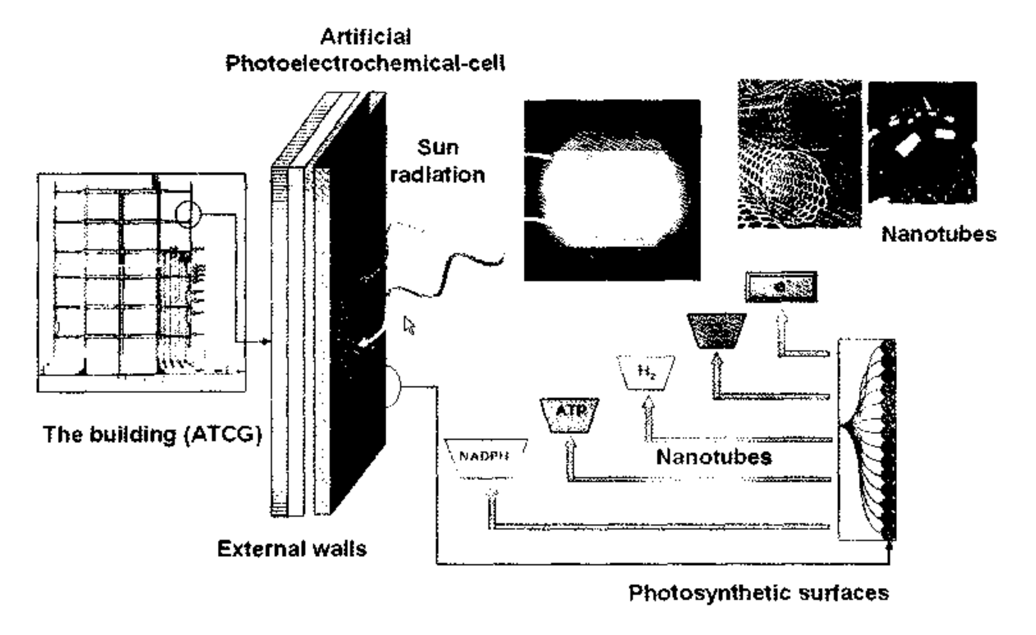

Fig. 2 Electrochemical energy collection; ATCG, Agricultural Transformation Clustered Greenfactories; ATP, adenosine triphosphate; NADPH, chemically reduced form of nicotinamide adenine dinucleotide phosphate

energy conversion (Fig.2).

The external walls of the building will be formed by a double polycarbonate layer, filled with a mimicked vegetal photosystem that will convert photons in electrons [adenosine triphosphate (ATP), chemically reduced form of nicotinamide adenine dinucleotide (NADH)] by means of photosynthesis, capable of feeding the production units inside the building. The oxygenic photosynthesis, the reaction centre of Photosystem II in plants, is the key to the most successful solar energy converting machinery on earth.

The water oxidation is catalyzed by a manganese cluster and it is an abundant source of electrons, H_2 and O_2. The H_2 and O_2 will percolate along nanotubes. They will be used in fuel cells for electricity production (Terrones & Terrones, 2004; Sun et al., 2003; Hammarström, 2003; Ferreira et al., 2004).

For this application, fullerenes present a wide range of chemical and physical properties that make potential chromophores in photoinduced redox processes. A hybrid consisting of Anthracene, fullerenes and fluorescein, acts as an antenna collecting light in the range of 320 - 400 nm, transferring its energy to the reaction centre, fluorescein. The fluorescein can absorb the light in the visible region (400 - 600 nm) and transfer an electron to fullerenes, generating a charge separated state (Jing & Zhu, 2004; Bourianoff, 2004). All the components involved in the charge transfer are designed to possess redox properties to maintain the directionality of the electron transport. Besides that, their disposition mimics the highly organised natural structure.

The ordered artificial system is achieved by incorporating those components in a biomembrane, called a primary biomembrane. This membrane also plays a fundamental role in the generation of the proton gradient for the synthesis of ATP, as occurs in the natural process. The primary biomembrane is bound to a second biomembrane, called a supported membrane (Bengt Kasemo, 2002). A fluid-like space connects both membranes. In this region, the ATP and the NADPH are accumulated. Special 'captor' proteins drive these products through the second biomembrane which is permeable to them. The supported membrane is deposited on a polycarbonate surface. Such a surface possesses suitable topographic, chemical and electronic properties to adsorb and retain the supported membrane. The surface is made by a nanoporous polymer. When the ATP and the NADPH reach the surface, driven by the 'captors', they are released. By means of pulsed concentration gradients, the photosynthetic products percolate along the nanoporous matrix towards specific reservoirs. These reservoirs provide the production units inside the ATCG with such products when they are required for chemo-enzymatic metabolic processes.

The ATCG will also obtain energy in other ways. Photoelectrochemical cells will transform the solar power directly in an electrical current. These systems will be based also on carbon (nanotubes and fullerenes). The conductive substrate of the cell will be nanotubes of carbon doped with a metallic element (Rius de Riepen & Castro Acuña, 1996; Zavala López & Vasilievna Kharissova, 2002). Solar plates around the base of the building will warm the air. Hot air flows up inside the building and drives turbines that will produce electricity. This airflow also provides the necessary gas mixture (oxygen, carbon and nitrogen) for food production. The nitrogen in the air will be fixed by means of genetically modified micro-organisms, living inside structural cavities inside the ATCG. This organically obtained nitrogen will be used to produce chemical compounds of different order (Smil, 1997; Ludden & Roberts, 2002; Berman-Frank et al., 2003).

Another function of the ATCG will be to recycle residual water. This water flows through a microbial fuel cell, where bacteria will metabolize their substrate – in this case, organic matter in wastewater – to release electrons that yield a steady electrical current (NFS & Office of Legislative and Public Affairs, 2004).

Production

The basic production unit in the ATCG will be the meristematic terminal (MT), using 'in vitro' culture technology (see Fig. 3). It will consist of a scarcely differentiated plant tissue, fixed inside a container. Dozens of MTs will be placed on shelves in the different floors of the ATCG. Each floor will be devoted to the production of one type of raw food. By the year 2200 seed companies and tree nurseries will adapt its production practices to sell MT replicates for food production using 'in vitro' culture technology.

The MT will be able to produce the edible part of the crop (not the entire plant) when it is stimulated to do so. By means of silencing the genes that control the production of plant parts without commercial interest, the MT will generate only parts of the crop with agricultural interest, for example fruits without leaves or branches.

The control of totipotency allows the formation of any part of a crop out of meristematic cells supplied with the correct nutrients and energy. Meristematic cells inside each MT units will be surrounded by a liquid medium ('cellfood') based on deuterium sulphate to dissociate the particle of water in to hydrogen and oxygen, permitting cell respiration. The energy caption systems and mass transformation tanks will feed the MTs.

The liquid medium will provide also the necessary nutrients for the correct growth of the crop. The growth culture will be liquid to permit its change depending on the development stage of the cultivation: for example, control of hormones and growth regulators in each one of the phases of production. Parameters such as pH, temperature, lighting and the rest of factors that can influence the cultivations will be controlled, also by means of electrochemical sensors and micro injectors, to maximize production and optimize food quality (Pelacho Aja et al., 2002).

ATCG will produce food but also materials for general use and also for its own internal needs. For example, at present the nanotubes are obtained by physical and chemical systems (Terrones & Terrones, 2004) but in the ATCG, genetically modified organisms will possess the metabolic routes necessary for obtaining the nanotubular compounds (Koza et al., 2003; Maddox, 2000; Alcalde, 2003).

Production control

Control, monitoring and stimulation of MTs will be done by a combination of biochemical pathways, electrochemical interfaces and biosensors. Genetic vector nanorobots will start the metabolic routes needed to produce each crop, by stimulating/silencing of genes. Biosensors used in the ATCG have been improved using nanotechnology. Some of the nanoparticle based sensors include the acoustic wave biosensors, optical biosensors, magnetic and electrochemical biosensors.

Advances in the carbon-based processors and photonic nanocomputing will make possible to interact electronically with each MT. Every group of production units (ATCG floors) will exchange information wirelessly with the distributed computing network of the ATCG. Artificial intelligence based on fuzzy neural networks will control the basic principles of production. Interaction with external computing networks will adjust production to consumer and processing industry actual demands.

Harvesting will be carried out by nanotechnology based robot swarms and macrorobots inside the building (Kondo & Ting, 1998), using machine vision and organoleptic sensors. Regarding the sub-topics including in robotics technology, e.g. manipulator mechanism and its control, end-effector design, sensing techniques, mobility and work cell development, it is easily understandable/imaginable as a feasible solution for harvesting products in the ATCG. Both cultural and environmental conditions in the ATCG will be controlled, decreasing the variability that must be taken into consideration in the robot design. In addition, work objects could be positioned in front of the robot by means of coordinated conveyors, simplifying the travelling devices for the robots and their work envelopes.

An external visual sensor based on red/green/blue (RGB) signals will enable discrimination between the work objects and the rest of the transport systems, where the products will be moving. The end-effector mechanisms will have specific designs depending on the work objects but a simple pneumatic suction system could be common in all cases. The products will be transported to the storage space through conduction by airflow.

In the year 2200, it will be possible to construct and deploy legions of micro-robots, as small as a grain of salt or smaller. This possibility is made apparent by recent progress in the fabrication of extremely small leg-like actuators for microelectromechanical systems (MEMS) and by progress toward the fabrication of ultra-densely integrated electronic nanocomputers. The integration of MEMS and nanoelectronics for the construction of such micro-robots in vast numbers is an obvious application of the rapidly advancing techniques for the economical fabrication of nanometer-scale structures, i.e. 'nanofabrication'. Micro-robots made via contemporary techniques for nanomanipulation and nanofabrication are a logical next step toward the more difficult, longer term goal of constructing artificial nanometer-scale machinery, such as molecular assemblers.

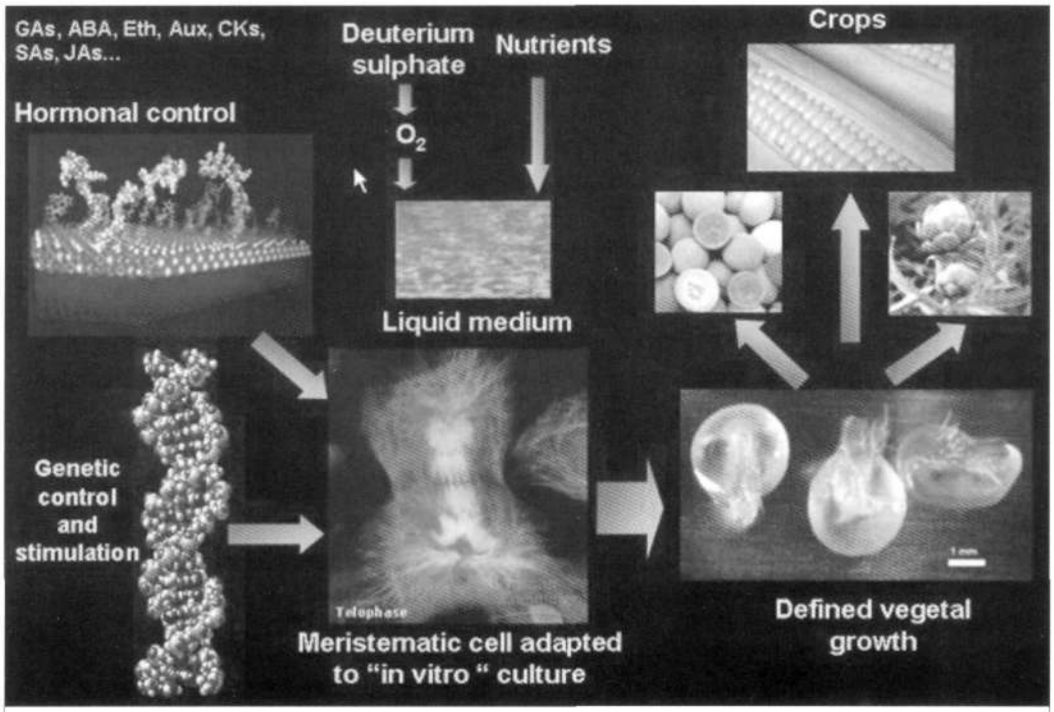

Fig. 3 Meristematic terminal culture; GAs, giberellins; ABA, abscisic acid; Eth, ethylene; Aux, auxins; CKs, cytokinins; SAs, salicylates; JAs, jasmonates

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Professor Ettore Gasparetto (left) who presented the award on behalf of the sponsors UNACOMA to the winning team (standing, from left to right):Teresa Riquelme (with the prize money!), Jose Rodriguez, Natalia Hernandez, Luis Ruiz, Belen Diezma, Maria Marin, and Victor Gil; and in front displaying the award certificate, Pablo Gutierrez (left) and Constantinos Valero [Photo courtesy: Mike Hurst]

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EurAgEng's 'UNACOMA Vision' event

Two papers, one on Bionic Buildings and the other on Robotics, were entered for the UNACOMA Vision event which took place as part of AgEng 2004 in Leuven, Belgium in September 2004. The European Society of Agricultural Engineers (EurAgEng) invited 'visionary people from the younger age group' to answer the questions of 'what can agricultural engineering do for society?' and 'what will agricultural engineering look like in the future?' Taking the form of a competition, 'young people' of aged 35 or under presented papers with their vision of the future of agriculture and technology in agriculture. Entrants were allowed to bring details of inventions and prototypes to demonstrate their vision, with the emphasis on looking forward, not looking back at work already done. The ideas had to show lateral thinking and consideration of ecological and economic factors had to be taken into account. The Vision event was sponsored by the Italian Machinery Manufacturers' Association (UNACOMA).

The two submissions for the UNACOMA Vision event were highly commended by the judges drawn from the EurAgEng Council – Professor Bill Day (EurAgEng President), Professor Ettore Gasparetto (Italy) and Professor Brian D Witney (UK) -- and oral presentations received well deserved praise from a large audience of conference delegates. Congratulations to all the contestants for their commitment and enthusiasm as they embark on their careers in biosystems engineering.